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Smart home technology enabling flexible heating demand: implications of everyday life and social practices

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Keywords

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Abstract

Integrating households into the energy system is considered a potential strategy for a low-carbon future, where balancing energy production and consumption becomes a challenge due to the intermittent and fluctuating nature of renewable energy sources. Time shifting electricity demand related to appliance use or heat pump production has been a focus in recent research, whereas heating consumption in district heating systems has received less attention. However, smart home technology (SHT) has been highlighted as a solution in which increased automation of heating could lead to balancing the supply and demand. SHT can enable households to be flexible energy hubs where heating can be stored, time shifting energy consumption to avoid peak-demand problems. Based on a review of the technical components of SHT, combined with a review of user engagements with SHT, we create a classification of SHT in a district heating system. Exploring several cases in real-world settings in the context of Denmark, we highlight the implications of everyday life and social practices when integrating SHT for enabling a flexible heating demand. While SHT may empower users with control of space heating (increased awareness and engagement with heating consumption), new notions of comfort and convenience may result in new and more energy-demanding practices, resulting in less flexibility within the district heating system. Based on these reviews, this paper underlines how active engagement with SHT is entangled in practices of everyday life and that, when integrating SHT to enable flexible heating demand in households, the role of everyday practices requires careful consideration.

Introduction

Energy efficiency remains at the core of political visions and policies of a low-carbon future together with the introduction of renewable energy sources (RES) into the energy system. Integration of RES into the energy system calls for storage possibilities and flexibility in demand due to the fluctuating nature of RES. Residential households consume a large share of the total energy consumption, as people perform everyday practices, such as cooking, bathing, or maintaining notions of comfort. Approximately 30 % of the total energy consumption in Denmark is used in residential households and the vast part of this for space heating (Danish Energy Agency 2018). The household sector thus holds potential for providing flexibility in demand in relation to integrating RES into the energy system. While some attention has been on the technological potential for enabling energy flexibility in the building stock by the use of SHT, less focus has been on uncovering how space heating is consumed by occupants, when SHT is integrated into the household. This paper aims at filling this research gap by reviewing the components of SHT for enabling energy flexibility within the district heating system and discussing how the implications of everyday practices interfere with such a potential.

Background

The most prevalent source of space heating in Denmark is district heating. The system has expanded since the 1970s, and today 64% of all Danish households are connected to the grid (Energitilsynet 2017). The long-term goal is a 90% RES-dependent district heating system in 2030, which has been reflected in the growing electrification of the system (e.g. through the promotion of large heat pumps to supply energy to the district heating system; Regeringen 2018). Future district heating systems must increasingly rely on fluctuating and intermittent energy, increasing the need for flexibility in consumption patterns and balancing district heat supply and demand. While research and experimental cases in real-world settings have investigated the use of SHT in relation to balancing electricity production and consumption (Christensen et al. 2017), less attention has so far been given to issues of including households in the balancing of space heating in a RES based district heating system. One reason is the opportunities for enabling flexibility in the district heating system, where energy can be stored in water tanks or in the grid itself (Lund et al. 2014), which is not possible in the electricity grid. On a system level, 4th generation district heating (4GDH) is an initiative focusing, among other things, on how different energy sources can be mixed at the production side, allowing greater flexibility in the energy system (Lund et al. 2014). Examining the opportunities for flexibility in the district heating system is important, as such opportunities can lead to increased flexibility in the energy system. In this respect, households can play a key role as hubs, enabling the flexible use of space heating, including the use of buildings as for storage of heat.

Consumption of space heating is characterised by mundane and habitual everyday practices, resulting in peak demands, typically in the morning, and smaller peaks in the late afternoon. Balancing the supply and demand of energy for space heating in a future RES-dependent district heating system is a challenge, and the focus has been on demand-side-management (DSM) initiatives and possibilities for time shifting energy demand (Nyborg and Røpke 2011). The integration of SHT in the building stock has been highlighted as important, as it enables automatic shifts in energy consumption, thereby utilising buildings as heat storage, avoiding problems of peak demand. This paper explores the implications of everyday life and social practices when integrating SHT, for enabling flexible heating within households. This is done by reviewing the literature on SHT and determining its core technological components. Based on this review, we will create a classification of SHT for enabling flexibility in a district heating system. This classification allows us to investigate how SHT is integrated into real-world settings. The literature review of user engagement with SHT raises important questions regarding what to consider when integrating SHT into the domestic sphere. Based on the literature review, we will conclude with a discussion on the implications of everyday life and social practices for engagement with SHT when integrating it in a district heating system.

Smart home technologies for enabling flexible heating demand

With the integration of information and communication technology (ICT) into the energy system, two-way communication between the supply and demand side has become possible. This has enabled the integration of technology aimed at shifting or reducing energy demand (Gellings 2009). In the following section, the focus will be on the technological components enabling energy flexibility. The SHT is the latest in a series of DSM initiatives aimed at reducing and/or time shift energy demand. Previous and popular DSM initiatives have included demand response, which relies on providing incentives to occupants who are then expected to undergo actions and lower or shift the energy demand(Karlin et al. 2014). While demand response initiatives are widespread (Joint Research Centre, European Commission 2018), they have mostly been focused on electricity use. In these cases, the academic literature shows multiple and varying results in terms of actual peak-shaving (Darby 2006). In recent years, the focus has been on building automation and control systems, which allows increased management of energy consumption (British Standards Institution 2017). This latest 'evolution' of DSM initiatives includes new means for peak-shaving and a possible more efficient use of energy. While a clear definition of SHT is not agreed upon in the literature, it is possible to identify several components that enable controlling and monitoring energy consumption. The five components of SHT are presented in the table below.

Thus, SHT differs from previous DSM initiatives by these different technological components. Moreover, communication networks allow monitoring and control of the metering and sensing components from a distance and enables different segments of the smart home (e.g. lighting and heating) to be connected to the same server or gateway (Balta-Ozkan et al. 2013, Lobaccaro et al. 2016, Strengers 2013, Withanage et al. 2014).

The means of control is a prominent part of SHT and is part of what differentiates SHT from other DSM initiatives. Control of SHT can be performed by the occupants of the households (e.g. using an in-house display or a smartphone) or by a third party, such as the utility company or building manager (Lobaccaro et al. 2016). While SHT often relies on users being in control, technical components of SHT include completely automated and autonomous processes of energy management (van der Werff and Steg 2015). Such systems often rely on algorithms predicting occupant behaviour (Ford et al. 2017). In the literature, the potential energy savings of integrating SHT have been

Table 1. Technical components of smart home technology (SHT).

Component	Function
Measurement devices (e.g. smart meters)	Time-based measurement of energy consumption
Sensing devices	Detection of data, such as temperature, occupancy, and humidity
Communication networks	Allows monitoring and control of the metering and sensing technology from a distance (e.g. Bluetooth, Z-wave, Zigbee, and Wi-Fi)
Energy smart devices	Appliances with integrated communication technology e.g. smart thermostats
Gateways/hubs	Platforms from which users can monitor and control settings, of multiple connected smart devices.

investigated (Yang and Newman 2013). As with other DSM initiatives, the results are manifold and conflicting, ranging from negative to positive savings (Ford et al. 2017). Despite this, the technical components of SHT entail increased potential for enabling flexibility in heating demand, and as a result, it has become a popular DSM initiative (Ford et al. 2017, Withanage et al. 2014). While the potential for peak-shaving is present in the technical components, so is the potential for increasing the levels of comfort and convenience (Lobaccaro et al. 2016, Strengers and Nicholls 2017). This has been highlighted as a performance gap and expresses how technology and material aimed at providing energy efficiency collide with the notions of comfort and convenience, offsetting the potential for enabling flexibility (Strengers and Nicholls 2017). Performance gaps have often been explained by unpredictable human behaviour, calling for the need for DSM initiatives to consider social and contextual factors (Ford et al. 2017, Coleman et al. 2015, Gram-Hanssen and Georg 2018). In the next section, we elaborate on how users engage with SHT. By reviewing the literature of user engagement with SHT, we highlight that energy consumption is entangled in everyday practices.

User engagement with smart home technology – a practice theoretical scope

In the literature, user engagement with SHT has been covered (Wilson et al. 2015, Gram-Hanssen and Darby 2018), however most researchers have examined the functional benefits and disadvantages of SHT (e.g. in relation to health) or the instrumental implications of such technology (e.g. if SHT is able to deliver energy savings). Less research has examined user engagement with SHT and the implications in a larger socio-technical system. One of the first studies applying this scope was conducted in 2007, examining the use of SHT in an Orthodox Jewish family (Woodruff et al. 2007). Studies examining user engagement in a larger socio-technical system differentiate from other studies of SHT, as SHT is perceived as inseparable from everyday practices.

Such research is in line with the theories of practices, which examine SHT as a material object deeply intertwined in everyday life. Grounded in the grand theories of Pierre Bourdieu (1977) and Anthony Giddens (1984), since the late 1990s, Theodore Schatzki (1996) and Andreas Reckwitz (2002) have unfolded theories of practice. Social practices are perceived as the central unit of analysis in any social context (Reckwitz 2002), as social order is a dynamic mixture of relations between all actors (human and non-human). Analysis of SHT must consider the issue of user engagement and examine how SHT is used, by whom, in which context, and for which activities. In terms of theories of practice, any analysis of social order must uncover the doings and sayings of everyday life to understand the use of SHT (ibid.).

With a focus on consumption, Alan Warde (2005) specified that consumption is a moment in every practice, and to understand consumption, one must understand practice (ibid.). In the words of Warde, understanding consumption implies understanding 'Why do people do what they do?' and 'How do they do those things in the way they do?' (2005, p. 140). Energy consumption is perceived as part of everyday practices, and investigations of energy flexibility must uncover the practices related to the consumption of energy (Shove and Walker 2014). In this scope, SHT is considered an element of practice and must be analysed in relation to both the competences and social meanings ascribed to that specific practice.

Situating engagement with smart home technology in everyday practices

In the literature, the use of SHT has been examined empirically in relation to the electrical grid (Nyborg and Røpke 2011). The results show that when integrating SHT in households energy consumption might increase, as new energy-demanding practices are normalised by the users (ibid.). Despite this, another study on the use of SHT in the electric grid in Denmark found that users are seldom represented in real-world experiments concerning SHT (Hansen and Borup 2018). Such perceptions are often translated into the need for further automation of SHT so that 'unpredictable human behavior' will have less influence on the potential of SHT for enabling flexibility. Another study examined the use of smart thermostats within households (Yang and Newman 2013). The results show that smart thermostats can generate user awareness of energy consumption and increase user engagement (ibid.), which has also been found regarding visualisation and feedback on energy consumption (Hargreaves et al. 2013). While the study on smart thermostats showed that some users perceived the technical functions as useful and felt in control, other users found the smart thermostats less useful and had difficulty understanding the logic behind the system (Yang and Newman 2013). This resulted in users creating workarounds and developing new practices to adapt the smart thermostats to their everyday lives. These results highlight the importance of including the understanding of everyday practices when studying SHT. Engagement with SHT is diverse and multiform, just as everyday life is (ibid.).

Comparable results were found by Marikyan et al. (2019) in a literature review of engagement with SHT. They found that many users perceived SHT as less useful and expressed a lack of knowledge, trust, and experience in engaging with SHT (ibid.). In a recent study on engagement with SHT in real-world settings, Hargreaves et al. (2018) concluded that, as everyday life is characterised by breakdowns and irregularity, SHT must adapt to this. The SHT must be easy for users to control, and the designers of SHT must be aware of not taking away control from users (ibid.). This emphasises the need for understanding competences as being diverse and that engagement with SHT is dependent on how users have previously engaged with (similar) technology. In empirical studies of engagement with SHT, the initial use of SHT is often driven by a single user, often the most technically proficient (Ibid.). Users who initially engage with SHT are not necessarily those who become the main users of SHT, as the practices for which SHT is used are performed by other household members (e.g. the one who is usually at home). Thus, SHT has the potential to reconstruct and disrupt structures within the household, such as gender dynamics (ibid.). Similar findings were presented by Mennicken and Huang (2012). Studying the motivations for acquiring SHT, they found multiple motivations ranging from hobby interest to positive experiences from a previous engagement with similar technology (ibid.). They also found that it is often the most technically proficient individuals who are involved in acquiring and implementing SHT in the household. Strengers found comparable results, specifying that the industry visions of users operating SHT rely on the so-called Resource Man (white technically proficient male), meaning that SHT fails to consider the complexity of everyday life and the importance of differences in the performance of social practices (Strengers 2013).

Implications of comfort and convenience

Within industry perceptions of SHT, control is a principal component, as it enables increased flexibility and energy savings without compromising levels of comfort and convenience (Hargreaves and Wilson 2017). From an industry viewpoint, increased automation of SHT is key in this process (ibid.). Users are merely perceived as those who delegate control to the technology (e.g. by indicating preferences or schedules; ibid.), and SHT will then manage the energy consumption in the most efficient way. The results from the literature show that some users feel a loss of control (due to increased automation) and perceive SHT as useless (ibid.). As a result, increased automation of space heating within the household might result in users questioning whether SHT is operating correctly and creating workarounds to compensate (ibid.). Empirically, it has been shown that user engagement with SHT is limited over time and that users create workarounds, while some completely reject SHT due to the inability to cope with irregularities in everyday life (ibid.).

As previously mentioned, the industry perception of SHT is that of both flexibility and energy savings, as well as comfort and convenience. Herrero et al. (2018) argued that SHT might increase energy consumption, as it reinforces and increases notions of convenience and comfort. The industry perception of SHT depicts users as both rational and utility maximising, knowing how to operate SHT as intended, and thereby achieving energy flexibility, energy savings, and increased levels of comfort. Such depiction does not correspond with the complexity of everyday life (ibid.). Promoting these visions might lead to a failed user adaption to SHT (e.g. scaling back SHT or failing to achieve energy savings and flexibility). In another article by Strengers and Nicholls (2017), further evidence for such claim was found. Strengers and Nicholls argued that visions put forward by the SHT industry promote SHT as part of a simple and convenient lifestyle, in which engagement with SHT will generate new forms of enjoyment within households and increase the level of comfort (ibid.). These conflicting visions of convenience and comfort, while promoting the potential for enabling energy savings and flexibility, are problematic, as convenience is a dynamic term and does not hold any final endpoint (ibid.). As engagement with SHT is envisioned as something that makes domestic life more convenient, convenience also becomes an integrated part of the process of saving energy and enabling flexibility (ibid.). The risk of such a vision is that energy management within the household becomes dominated by a vision of simplification, convenience, and comfort, resulting in an increased level of energy consumption (ibid.).

In the following sections, we will uncover how cases of SHT integrated into households in real-world settings in Denmark are unfolded. We created a classification representing the core issues of SHT in a district heating system. This classification allows further discussion on the implications of everyday practices when SHT is integrated into a district heating system.

Case selection

The case selection is conducted in two rounds to locate the most relevant cases for the scope of this paper. The first selection consists of a total of 155 cases. These cases are selected as relevant, as they all included an aspect of SHT (in broad terms) which are integrated into households with the aim of shifting or reducing energy demand. The second selection of cases narrows the 155 cases to 21 cases. The 21 cases are selected on the basis that they all concerned with SHT integration in Danish households and are in a district heating system. Furthermore, the 21 cases all fulfilled the criterion of SHT being in the 'latest' evolution, meaning that users had the ability to both control and monitor energy consumption. The 21 final cases are the following:

1. Located in a district heating system,
2. Located in Denmark,
3. Use advanced SHT, and
4. In real-world settings.

The final selection of cases provides an overview of cases experimenting with SHT in a district heating system and as such provides insight into how different cases in real-world settings are integrated into a district heating system. The cases have been located and selected based on a document study using both public (Google and Infomedia) and research databases (Scopus and Energiforsk). Some cases involving SHT in a district heating system may not have been included, e.g. due to the lack of available information, including cases where individual households have bought SHT and installed it on their own initiative. To compensate for such a methodological approach, market statistics of SHT related to energy management have been included in the analysis. The market for SHT related to energy management is manifold and consists of multiple commercialised products (e.g. Danfoss, Nest, Bosch, EcooBee, Fibaro, TADO, and Netatmo). Including market statistics on SHT provides valuable information on market trends, including the penetration rate in Danish households and the technological components of SHT in commercialised products.

A classification of SHT integration into the Danish district heating system

A classification of the how, who, and what of SHT in a district heating system has been developed as an analytical tool. This classification has been developed based on the literature review introduced earlier, and the three parameters express the central aspects of control of SHT in a district heating system. Figure 1 presents a graphical representation of the how, who, and what of SHT in a district heating system.

The how of SHT in a district heating system represents the technical components. The how of SHT is relevant to determining how control is performed (e.g. using simple controls or programmable features of the technical setup). Regarding the technical components, some SHT is more advanced than others in the technical setup. While simple controls represent the most direct form of engagement with SHT, model predictive control (MPC) represents a much more advanced form of control in which algorithms based on input from sensors auto-

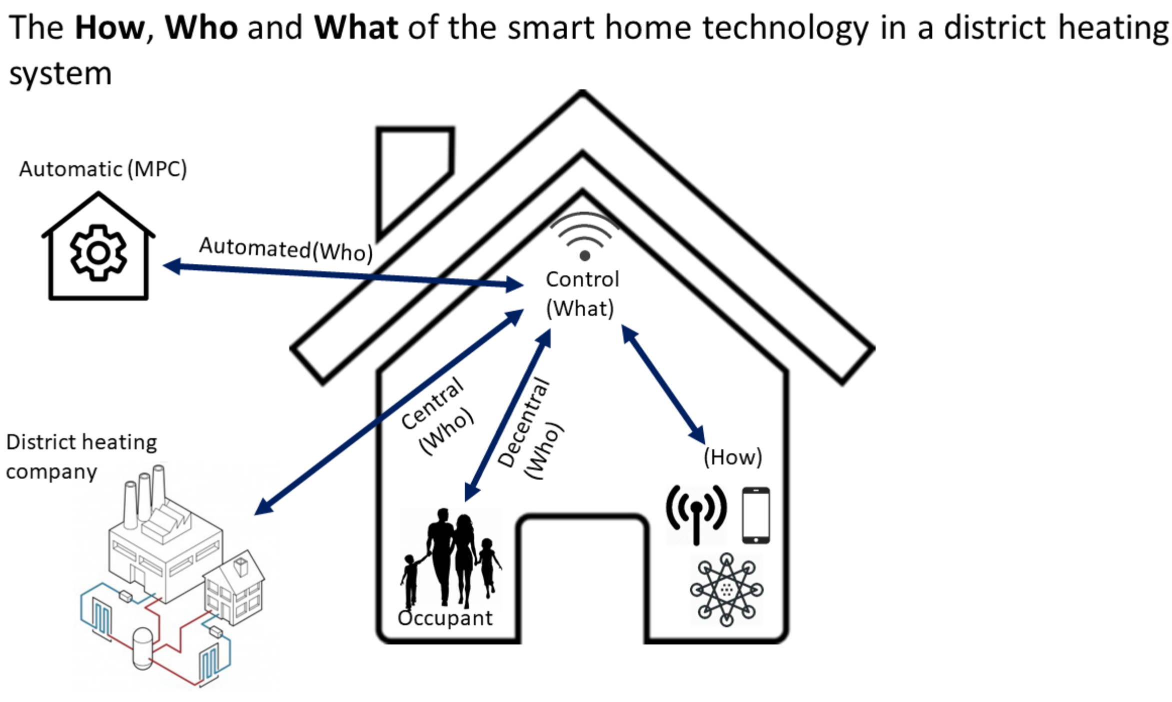

Figure 1. The how, who, and what of smart home technology (SHT) in a district heating system.

matically allow control of SHT. The how of SHT is also strongly relevant to the who of SHT, as technological components script the control performed by certain actors (e.g. MPC scripts automatic control).

The who of SHT in a district heating system expresses the actors involved in the control of SHT. In this classification, centralised, decentralised, and automated control are distinguished. Centralised control is when third-party actors perform the control, either the district heating company or building manager. In such cases, these actors directly perform the control (e.g. putting up set-points to the grid or controlling individual space heating directly, such as in the Sundmolen case). On the other hand, decentralised control is control performed by actors within the households (i.e. the occupants). The occupants do not necessarily need to be within the household to perform control, as this can be done at a distance using smartphones, for example. The last form of control is defined as automated. Automated control relies on mathematical algorithms calculating different forms of data from sensors, such as weather conditions, grid capacity, and occupant behaviour. Based on this data, a model of prediction (MPC) is typically generated, and control is exercised based on this (Shaker and Lazarova-Molnar 2017, Scott et al. 2011).

The what of SHT in a district heating system expresses the issue of what is being controlled. The what of SHT expresses distinct types of communication modules included in SHT (Z-wave, Wi-Fi, or Bluetooth). In this classification, we differentiate between stand-alone solutions and integrated solutions. Stand-alone solutions are isolated solutions that serve a single purpose within one segment of a smart home (in this case, space heating). An example of such technology includes smart thermostats. In contrast, integrated solutions can control multiple segments of a smart home (e.g. heating, lighting, etc.). Based on the classification of the how, who, and what of SHT in a district heating system, the 21 cases have been reviewed and classified. A further column expressing the incentives (as stated by the project manager) to integrate SHT into the concrete cases has been included in the table. This reveals insight into why some cases experiment with centralised rather than decentralised control.

Results

Table 2 summarises the 21 cases integrating SHT into a district heating system. Based on our classification of the 21 cases, in which SHT has been integrated into households in a district heating system, our findings suggest that both simple control solutions, in which users interact directly with the technology, and automation solutions relying on both sensor inputs and user input (rule-based and schedules), apply as the means of *how* to control space heating. This combination of different means to control SHT reveals the importance of SHT empowering users to feel in control while doing so conveniently, ensuring a minimum of discomfort for the user. Furthermore, by applying advanced technological solutions that rely on machine learning (for example), users can automate the control of space heating based on set-and-forget features or rule-based inputs (e.g. schedules), while having the opportunity to override this automatic control. An example is found in the RESPOND case. In this case, control of space heating is based on a rule-based system, in which the households are heated before peak hours, resulting in increased flexibility within the district heating grid. The users can override such 'rules' and control the space heating directly, adding comfort to their everyday lives.

With regards to *who* controls the SHT, MPC is found in five cases. Relying on several inputs (e.g. weather data, occupant behaviour, and grid capacity), the MPC calculates the predicted energy demand within the individual household and applies

Table 2. Cases on smart home technology in a district heating system.

Case name and project manager	How	Who	What	Why (Incentives)
Bolig+[1] (Philanthropic Association)	Simple control, set and forget	Decentralised	Stand-alone solution (Z-wave)	Reduce energy demand, improve indoor climate and comfort
Havnekanten, Energy Lab Nordhavn[2] (Research institute)	Simple control, set and forget, set-points, MPC	Centralised, decentralised	Stand-alone solution (Wi-Fi)	Time shift energy demandImprove indoor climate and comfort
BetterHome[3] (Private co.)	Simple control, set and forget	Decentralised, automated	Stand-alone solution (Wi-Fi, Bluetooth)	Reduce energy demand, improve indoor climate and comfort
Vedvarende energireduktioner[4] (Public housing association)	Simple control, set and forget, MPC	Decentralised, automated	Stand-alone solution (Bluetooth, Wi-Fi)	Reduce energy demand
Sundmolen, Energy Lab Nordhavn (Research institute)	Set-points, Simple control, set and forget	Centralised, Decentralised	Stand-alone solution (Wi-Fi)	Time shift energy demandwithout decrease in comfort
Frihavnstårnet, Energy Lab Nordhavn[5] (Research institute)	Set-points, Simple control, set and forget	Centralised, Decentralised	Integrated solution (Wi-Fi)	Time shift energy demandwithout decrease in comfort
Albertslund konceptet[6] (Municipality)	Simple control, set and forget	Decentralised	Stand-alone solution (Z-wave)	Reduce energy demand
Rækkehusene, Energy Lab Nordhavn, (Research institute)	Simple control, set-points, rule-based	Centralised	Stand-alone solution	Time shift energy demandwithout decrease in comfort
MCHA: Minimum Configuration – Home Automation[7] (Research institute)	Rule-based, simple control, set and forget	Decentralised	Integrated solution	Reduce energy demand, improve indoor climate and comfort
MiniCO2 Husene – Kvotehuset[8] (Philanthropic Association)	Simple control, set and forget	Decentralised, automated	Integrated solution	Reduce energy demand
PreHEAT for District Heating[9] (Private co.)	MPC	Automated	Stand-alone solution	Time shift energy demandwithout decrease in comfort, Reduce energy demand
Two private households in Sønderborg Municipality[10]	Simple control, machine learning, set and forget	Decentralised	Stand-alone solution (Wi-Fi)	Reduce energy demand
SmartHjem Varmestyring[11] (Utility co.)	Simple control, set and forget	Decentralised	Stand-alone solution	Reduce energy demand
Ryesgade 25 + 30[12] (Private company)	Simple control, set and forget	Decentralised	Integrated solution (Wi-Fi)	Reduce energy demand, improve indoor climate and comfort
Revalue[13] (Research institute)	MPC, set and forget	Automated, decentralised	Integrated solution	Reduce energy demand, improve indoor climate and comfort
RESPOND[14] (Research institute)	Simple control	Automated, centralised	Integrated solution	Time shift energy demandwithout decrease in comfort, Reduce energy demand
Sunde boliger[15] (Philanthropic Association)	Simple control, set and forget	Decentralised	Stand-alone solution	Improve indoor climate
VPP4SGR – Virtual Power Plant[16] (Research institute)	MPC	Automated	Stand-alone solution	Time shift energy demandwithout decrease in comfort, Reduce energy demand
Villa in Vestbjerg[17] (Private household)	Simple control, set and forget	Decentralised	Integrated solution	Improve indoor climate and comfort
Procesværktøjer til 360° indeklimarigtig energirenovering[18] (Private co.)	Simple control	Decentralised	Integrated solution	Reduce energy demand, improve indoor climate and comfort
EnergyFlexHouse[19] (Research institute)	Simple control, set and forget	Decentralised, automated	Integrated solution	Time shift energy demand
CITIES – Center for IT Intelligente Energi Systemer i Byer[20] (Private co.)	MPC	Automated	Stand-alone solution	Time shift energy demand
The Silo, Nordhavn[21] (Private co.)	Simple control, set and forget	Decentralised	Integrated solution	Reduce energy demand, improve indoor climate and comfort

[1] *http://www.boligplus.org/forside2/data-for-bolig-i-soborg*

[2] *http://www.energylabnordhavn.com*

[3] *https://www.betterhome.today/, EnergyPackage*

[4] *https://inno-se.dk/projects/vedvarende-energireduktioner/*

[5] *http://www.abb.dk/cawp/seitp202/36eac64a94d-3225ac12580c1003502f7.aspx*

[6] *http://www.bæredygtigebygninger.dk/media/1973/brochure-albertslund-konceptet.pdf*

[7] *https://develco.dk/minimum-configuration-home-automation-mc-ha/*

[8] *https://www.realdaniabyogbygklubben.dk/media/232524/kvotehuset.pdf*

[9] *http://neogrid.dk/preheat/?lang=en*

[10] *http://www.projectzero.dk/da-DK/Borger/ZERObolig/ZEROmap/Energirigtig-adfærd/Store-besparelser-med-ren-teknologi.aspx and http://www.projectzero.dk/da-DK/Borger/ZERObolig/ZEROmap/Energirigtig-adfærd/Smarte-termostater-og-energirigtig-adfærd.aspx,*

[11] *https://csr.dk/nedsæt-varmeforbrug-med-ny-dong-applikation and https://www.se.dk/smarthome/intelligent-varmestyring*

[12] *http://docplayer.net/47317139-Urban-innovation-for-liveable-cities.html*

[13] *http://amplex.dk/references/amplex/revalue/*

[14] *https://get.dexma.com/hubfs/RESPOND%20Deliverables/RESPOND_1-4.pdf?utm_campaign=RESPOND&utm_source=RESPONDPublicationsWeb*

[15] *https://realdania.dk/publikationer/realdania-by-og-byg/sunde-boliger---midtvejsrapport*

[16] *https://energiforskning.dk/sites/energiteknologi.dk/files/slutrapporter/12019_-_final_repor_vpp.pdf*

[17] *http://www.nt-el-service.dk/referencer/vores-referencer/abb-free@home*

[18] *https://static1.squarespace.com/static/53996805e4b08b1a1a83f62c/t/54d34e1ae4b0b989938b8078/1423134234521/Develco+Products+erfaringer+i+projektet+dec+2014.pdf*

[19] *https://www.teknologisk.dk/laboratorier/energyflexhouse/byggeriet/25280,5*

[20] *http://smart-cities-centre.org/wp-content/uploads/Control-of-heat-pumps.pdf*

[21] *https://www.pettinaroli.dk/om-pettinaroli/referencer/case-the-silo-nordhavn/*

control accordingly in a completely automated manner (e.g. lowering the supply temperature). Cases applying MPC seem more focused on optimising grid capacity and enabling flexibility, which are also expressed in the stated incentives (the why).

In the cases of Sundmolen and Frihavnstårnet, control is performed centrally (by a third party), but a simple form of how to control is still applied. In these cases, set-points (of optimal grid flow) are applied by the district heating company, lowering the space heating temperature during peak hours. The occupants do not have the opportunity to overrule the set-points. An important incentive for integrating solutions with centralised control seems to be the possibility for enabling grid flexibility. In the commercialised market for SHT, products apply a simple and decentralised form of control in combination with automated control solutions (Statista 2018). In the context of space heating, smart thermostats are the most common SHT within residential households and are expected to reach 22 million European households by 2020 (Statista estimates, IoT Now 2016). The smart thermostat typically applies both simple forms of control and (in more advanced forms) machine learning and the use of set-and-forget features.

In the 21 cases, we also find that decentralised control is most widespread, followed by the use of automated control. Again, it is worth noting that cases involving decentralised control often apply the use of automated control, allowing users to be directly involved in the control of the SHT while allowing some degree of automated control (often relying on different predictions and sensor technology). Centralised control is the least widespread solution in a district heating system, and only a few cases apply it. In the cases that apply a centralised form of control, research institutions are the main actors involved, and the cases can be characterised as experimental in their design. Centralised control is used with the primary aim of providing flexibility within the grid, and user perspectives of comfort are regarded as less important (compared to cases of decentralised and automated control). Centralised control is also integrated in combination with decentralised control solutions, which highlights that, even though such cases aim at increasing grid flexibility, a recognition of user comfort is prevalent, and decentralised control is considered the tool for obtaining it, highlighting that SHT that enables flexibility should not compromise user comfort.

Regarding what is controlled by SHT in a district heating system, we find that stand-alone and integrated solutions are equally represented among the selected cases. As stand-alone solutions have been part of the SHT commercial market for a long time and smart thermostats were adopted early by consumers (Ford et al. 2017), they are widespread within the domestic sphere and in our findings as well. Due to problems of interoperability (Balta-Ozkan et al. 2013) and an increase in automation of different segments of the household, more recent SHT solutions are developed as integrated solutions, solving the problem of different devices not communicating properly together (Marikyan et al. 2019). Integrated solutions allow control of multiple segments of the household and are especially used in newer buildings, in which the complexity of the smart home calls for an integrated system. This trend is followed by companies developing gateways, allowing different stand-alone solutions to be connected and controlled using one device (e.g. Google Home, Amazon Alexa, and Apple HomeKit). While these devices were not found in our classification of SHT in a district heating system, they are becoming increasingly widespread within the domestic sphere, allowing users to control lights and home entertainment appliances conveniently simply using voice commands. As SHT is becoming increasingly widespread, multiple segments of the home are being controlled using different SHT solutions. The influx of integrated solutions indicates that the increased complexity of the smart home has called for an increase in integrated systems, allowing the user to control the home conveniently and easily. While perceptions of SHT in a district heating system historically have been occupied with the control of space heating, more recent SHT has been applied and integrated into a more holistic understanding of the smart home, combining control of space heating with that of window shuttering and lighting, revealing increased visions of comfort and convenience.

Discussion and perspectives for future research

Our findings from exploring 21 cases in a Danish context suggest that SHT integration in a district heating system mostly relies on stand-alone solutions and decentralised control, which can be directly controlled and automated. As noted, such solutions offer users convenient control of energy consumption, securing increased comfort within the household. Current SHT focusses less on merely enabling flexibility or at least not compromising notions of comfort on the grounds of enabling flexibility. This is also reflected in the mixture of decentralised and automated control solutions. As mentioned, comfort is a dynamic term, meaning it has no endpoint. As SHT promotes comfort and possibilities of time shifting energy demand , they risk not achieving either one (Strengers 2008, 2013).

The influx of RES in the Danish district heating system calls for increased flexibility. Our exploration of 21 cases suggest that current SHT integration in the district heating system may not achieve flexibility. Only of few of the selected cases have flexibility as their main incentive for integrating SHT, and in these cases, centralised control is applied, in which user comfort is less prevalent. This highlights that decentralised solutions are not considered suitable for enabling flexibility and that automated and centralised control are believed to achieve better results in that regard. This suggests that occupants are not considered able to deliver flexibility to the grid, and the role of occupants is limited to ensuring the levels of comfort or managing energy demand conveniently. This suggests that SHT has been developed and integrated as a result of 'unpredictable human behaviour'. Where previous DSM initiatives have provided incentives to occupants, believing that they would time shift energy demand or lower the energy demand, results have shown that this has not been the case. Recent SHT aims at removing the 'human factor' with increased automation or centralised control. Such perceptions risk forgetting the implications of everyday practices and that SHT, although automated, cannot be removed from everyday practices. These results highlight the necessity of more research on how users engage with SHT. Further exploration can explain how users engage with SHT and provide feedback to SHT solutions on how to include and reconfigure everyday practices in a way that adds flexibility to the district heating system. Our findings show that, while stand-alone solutions are widespread, integrated solutions are slowly making their way into the household, allowing users to control multiple segments conveniently (e.g. one-button control of heating, windows, and lighting).

On one hand, SHT with automated control enables flexibility due to the ability to operate space heating based on inputs from both the grid (e.g. regarding when to peak-shave) and the domestic sphere (occupancy, behaviour, etc.). On the other hand, trying to quantify everyday practices in terms of occupancy and preferred behaviour (e.g. user input regarding whether the user is at home) can prove a challenge, as everyday life is also characterised by irregularity. With automatic control solutions for enabling flexibility, SHT might not succeed in doing so, as users create workarounds due to the inflexibility of automatic SHT. The results from other studies show that engagement with SHT, automatic or not, relies on competencies and the meanings users ascribe to space heating of the household, for example (Hargreaves et al. 2018). Furthermore, SHT acts as a disrupting technology. Through engagement (or the lack), social dynamics within a household might be reconfigured. In this respect, an analysis of engagement with SHT must include a wider socio-technical view and investigate how SHT reconfigures practices of space heating and related practices. Our findings show that cases involving automatic control also allow the possibility for users to overrule it.

As mentioned, our findings suggest that SHT solutions integrated into households use both automatic control (as the means of enabling flexibility) and decentralised control to compensate for notions of comfort. This suggests a perception of users as passive and unable to enable grid flexibility, delegating the responsibility solely to technology. The perception of users as passive is incompatible with what is known from the literature, where users often create workarounds if they do not know how to (or cannot) engage with technology in the intended way (Strengers 2008, 2013). Users tend to open windows, for example, and the intention of enabling flexibility to the district heating system may thus be restricted. Automation is not a complete solution for enabling flexibility, and everyday practices must also be targeted. This research gap highlights a need for deeper insight into how users engage with SHT, calling for further research.

While researchers have been investigating the use of SHT in the electric grid, to the best of our knowledge, there has been no focus on how users engage with SHT in a district heating system. As SHT acts as a disrupting technology within the home, such research should uncover how SHT reconfigures practices of space heating and notions of comfort. Does the integration of decentralised SHT in the domestic sphere generate new notions of comfort? How do practices of space heating and notions of comfort differentiate with different technological components and setups? Is user engagement with SHT necessary, or is it possible to increase flexibility without involving users? How are the control of space heating and practices of heating in general developed, if the control of heating is conducted by actors outside the domestic sphere (centralised or automated)? The classification of our 21 selected case indicates that these questions are worth investigating in further detail in a qualitative manner.

Conclusion

In this paper, we have presented a study on the integration of SHT in a district heating system. We explored and classified 21 cases of SHT integration in a district heating system. A discussion of how users engage with SHT has been the focus, and we highlight the implications of comfort, convenience, and everyday life as crucial for understanding the engagement with SHT and the possibility of enabling flexibility in the district heating system. We find that decentralised solutions are most widespread, highlighted the importance of occupants being in control of space heating and maintaining or increasing the level of comfort. The means for flexibility is integrated using automatic solutions, in which multiple inputs are considered. Automatic solutions are often integrated in combination with decentralised control, meaning that flexibility is only sought if it does not compromise user comfort. While automatic control can enable flexibility, there is a need to include users more in such solutions, and their everyday practices risk cancelling the intended flexibility. User involvement and decentralised control should therefore not only be limited to ensuring the notion of comfort and convenience but should also be actively used in a manner that can reconfigure space heating practice so that they can become more flexible. In future research, which this PhD is a part of, we intend to examine the use and engagement with SHT in a district heating system in detail.

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